Wang, Liyuan, Yan, Xueyuan, Fan, Binghui, Jin, Ruoyu, Yang, Tong ORCID logoORCID: https://orcid.org/0000-0002-1254-5628 and Kapogiannis, Georgios (2020) Incorporating BIM in the final semester undergraduate project of construction management — a case study in Fuzhou University. KSCE Journal of Civil Engineering, 24 (8) . pp. 2403-2418. ISSN 1226-7988 [Article] (doi:10.1007/s12205-020-1971-4)

Final accepted version (with author's formatting)

Incorporating BIM in the Final Semester Undergraduate Project of Construction Management–A Case Study in Fuzhou University

Article *in* KSCE Journal of Civil Engineering · June 2020

DOI: 10.1007/s12205-020-1971-4

To cite this article:

Wang L., Yan X., Fan B., Jin R.*, Yang T., and Kapogiannis G. (2020). “Incorporating BIM in the Final Semester Undergraduate Project of Construction Management-A Case Study in Fuzhou University.” *KSCE Journal of Civil Engineering*, In Press, Accepted for publication on 6 Apr 2020.

Incorporating BIM in the Final Semester Undergraduate Project of Construction Management-A Case Study in Fuzhou University

Liyuan Wang[1], Xueyuan Yan[2], Binghui Fan[3], Ruoyu Jin[4,*], Tong Yang[5], Georgios Kapogiannis[6]

[1]Lecturer, College of Civil Engineering, Fuzhou University, 2 Xue Yuan Road University Town, Fuzhou, China, 350116, Email:eyuan369@163.com
[2]Professor, College of Civil Engineering, Fuzhou University, 2Xueyuan Road, Fuzhou, Fujian, China 350116. Phone: +86 15280425642, Email: yxy820910@sina.com
[3]Lecturer,College of Civil Engineering, Fuzhou University, 2Xueyuan Road, Fuzhou, Fujian, China 350116. Phone: +86 18906901982 , Email: fanbinghui@fzu.edu.cn
[4]Senior Lecturer, School of Environment and Technology, University of Brighton, Cockcroft Building 616, Brighton, UK. BN2 4GJ. Phone: +44(0)7729 813 629, Email: *R.Jin@brighton.ac.uk*
[5]Senior Lecturer, Department of Design Engineering and Mathematics, Faculty of Science and Technology, Middlesex University, UK, Email:T.Yang@mdx.ac.uk
[6]Assistant Professor, Department of Architecture and Built Environment, University of Nottingham Ningbo China, 199 Taikang East Rd., Ningbo China. Email: Georgios.Kapogiannis@nottingham.edu.cn

*: Corresponding author

Abstract

This pedagogical study presents Building Information modeling (BIM) education in the final semester construction management (CM) program. The case study conducted in Fuzhou University extends BIM education from a single BIM course in earlier undergraduate years to the senior year’s final semester project, which was designed to enable BIM utilization in multiple construction tasks (e.g., 3D site planning). This study consists of two major parts. The first part starts with the newly designed course of the final semester project of CM students. Students’ final semester project work is demonstrated depending on their selected deliverable type, which includes full BIM application group work, two partial BIM application types (i.e., construction planning/scheduling, and take-off estimate), and a research dissertation. The second part starts from the research hypothesis of whether the different deliverable type selected by students would affect their perceptions towards the final project and their professional career. Based on a follow-up questionnaire survey to the whole CM student sample aiming to test the hypotheses with statistical analyses (e.g., Analysis of Variance and the post-hoc analysis), it was indicated that all the four different deliverable types (i.e., subgroups) could lead to consistent perceptions of the final semester project towards their career development. However, subgroup differences were found. For example, students from the subgroup of full BIM application perceived that they had the highest level of hands-on skill enhancement throughout the project, possibly due to the fact that they linked BIM software tools to Virtual Reality (VR) hardware. Suggestions were provided to update the future BIM pedagogy in the final semester project, such as proper guide of CM students to opt their project deliverable type depending on their career interests, motivations in BIM utilization, and skill development needs. This current study provides insights in BIM education in terms that: (1) BIM education could be enhanced from a single course level to the senior year project in the CM program level; (2) different options offered in the final stage project within the CM curriculum might affect students' perceptions towards BIM or their career development; and (3) the experience learned from this case study could be shared in the global community of construction education to update the curriculum incorporating information and communication technologies (e.g., BIM and VR). Future educational work in BIM could continue adopting existing educational theories (e.g., Bloom's Taxonomy) by addressing the various levels of student learning, and viewing BIM in the bigger picture of digital construction.

Keywords: Building Information Modeling (BIM); BIM education; virtual reality; construction education; construction management curriculum

1. Introduction

Building Information Modeling (BIM) has been gaining its momentum in the curriculum update of construction management (CM) and civil engineering (Chen et al., 2019; Zheng et al., 2019). BIM has been confirmed by both academia and industry as important (Solnoskyand Parfitt, 2015), especially in meeting the industry needs (Sacks and Pikas, 2013). The update of courses or curriculum to incorporate BIM in AEC (i.e., architecture, engineering, and construction) disciplines has been ongoing and led to more BIM education-based research (e.g., Bouska and Heralova, 2019; Zhang et al., 2019). There have also been some existing studies (e.g., Zhao et al., 2015; Shelbourn et al., 2017) targeting on students' perceptions towards BIM-related courses or curriculum. However, insufficient research has focused on applying the BIM-oriented digital platform in the CM program level as an extension from the BIM course level. For example, BIM adoption in the senior year or final semester project could integrate BIM with other CM core courses (e.g., scheduling and cost estimate). The reason to implement BIM in CM students' final stage of study is that it is students' transition period from college to the professional field, or in another word, pre-career training. There is a need to study how BIM could be integrated into the CM curriculum to enhance the connection among courses (e.g., BIM and cost estimate), as well as the effects of the integration. The benefits of the integration of BIM with other AEC courses could be foreseen in several BIM education-based studies, including Sharag-Eldin and Nawari (2010), and Solnosky and Parfitt (2015). To investigate the effects of BIM integration into the traditional CM curriculum (e.g., final stage capstone project), researchers in this study believe that a comparative subgroup analysis would allow a better understanding of BIM impact on CM students' learning curve in their capstone project. Students' subgroups are defined when they opt for full BIM, partial-BIM, or non-BIM approach to complete their project. How the different approaches affect students' perceptions could be studied upon the project completion. So far, this subgroup comparative method has not been widely adopted in investigating the effects of BIM integration into the CM curriculum. Nevertheless, the subgroup comparison approach could be adapted from another prior study in civil engineering education (i.e., Li et al. 2018).

As a step forward from integrating BIM into the traditional CM curriculum, Fuzhou University has been extending the BIM education in its CM curriculum by incorporating BIM in students' final semester project. BIM is utilized as the digital platform to assist a variety of construction tasks, for instance, 3D site planning, scheduling, take-off estimate, and integration with virtual reality (VR). Walker et al. (2019) proved the added value of using VR in order to improve Civil Engineering studies. On the other hand, although highlighting BIM in the final semester project is one of the major changes in the recently updated CM curriculum at Fuzhou University, curriculum leaders and other construction educators fully respect students' preferences in their project deliverable types. Before BIM was adopted in the CM curriculum, students were required either to complete the traditional research dissertation or to perform manual work in combination with CAD (i.e., Computer-Aided Design) to complete given construction tasks (e.g., scheduling). Before the commencement of the final semester in spring 2019, students were asked to select their own deliverable type for the last semester, namely full adoption of BIM through team project, partial BIM adoption through either teamwork or individual work, and the traditional research dissertation.

This BIM education-based study addresses the limitation of prior research by focusing on BIM adoption in CM students' final semester project, which required senior year students to apply their knowledge and skills developed from prior years' study in a real-world high-rise building project. The objectives of this study include: firstly, demonstrating how BIM has been utilized as the digital platform to assist the traditional construction tasks (e.g., cost estimate); secondly, capturing students' perceptions of BIM's impacts on their project, and their overall perceptions on the final semester project. The second objective is achieved through comparative subgroup analysis by dividing students into different project deliverable types, the namely full application of BIM, partial BIM application, and a research dissertation. This study provides insights into how BIM, either through full adoption or partial utilization, would impact students' perceptions towards BIM and their project. The current study contributes to the body of knowledge in BIM education both theoretically and practically. Theoretically, this research extends the undergraduate education practices (Chickering and Gamson, 1987) and Bloom's Taxonomy (Bloom, 1956) in the BIM-embedded CM curriculum. Practically, the detailed arrangement (e.g., timetable) and display of student project deliverables offer useful information to other peer educators on BIM curriculum update. Students' feedback following up their project completion also provide hints for both researchers in this study and peer BIM educators worldwide to continue enhancing CM education for college graduates to be better prepared in their professional career. Based on current work, more research-informed teaching (Healey, 2005) could be adopted in future BIM education, such as BIM linked to virtual reality and other digital technologies.

2. Literature Review

2.1. BIM practice and research

BIM has been gaining the growing use and rapid development in the AEC field's emerging practice and research (Zou et al., 2019b), for example, BIM integrated to Geographic Information System in construction engineering practice (Kim et al., 2016a), BIM applied in the integrated project delivery process to reduce change orders (Ma et al., 2017), BIM for historic building maintenance (Lee et al., 2019), and the cost-plus estimating framework integrating BIM (Koo et al., 2017). The increased and diversified BIM implementation in the global AEC industry has resulted in higher demand for college graduates with BIM skills (Suwal et al., 2014). It is indicated that BIM acceptance readiness (Lee and Yu, 2017) does not depend on current industry practitioners, but also university graduates (Zou et al., 2019a) who are the future AEC professionals. The assessment of BIM acceptance degree studied by Kim et al. (2016b) revealed that although the Korean AEC professionals generally held positive attitudes towards the necessity of BIM, they did not have strong intentions to accept BIM. Underwood and Ayoade (2015) stressed the challenges of BIM inclusion in the UK higher education, highlighting the disconnection between disciplines, lack of software tools' connections, and the insufficient understanding of BIM maturity levels. These findings spark the further research needs of extending BIM-related emerging research and practice into university education, as an approach to change the BIM acceptance level, as well as to enhance the integration of BIM in AEC disciplines including construction project management.

2.2. BIM education

Institutional education is important in the uptake of BIM (Suwal et al., 2014). A BIM-based review conducted by Santos et al. (2017) showed that more BIM-related studies had emphasized technical issues (e.g., interoperability), but BIM education-related research had been under-represented. BIM education is important because it works as a pre-career training to reduce the industry investment for employee training once college graduates enter the job market (Tang et al., 2015). Several existing BIM education-based studies (e.g., Kim, 2011; Nawari, 2015) had been focusing more on BIM utilization in a single discipline such as structural engineering. Nawari (2015) utilized BIM as the tool to teach the essential parts of structural design and to assist students' understanding of building systems and structural patterns. It was suggested that BIM teaching was not similar to the traditional Computer-Aided Design (CAD), but was more collaborative to enhance the learning of structural engineering. Kim (2011) applied BIM in construction education and found that BIM assisted students in a more effective learning of construction details and quantity take-off. A variety of BIM pedagogical strategies could be found in some existing BIM educational activities, such as collaborative teamwork (Mathews, 2013), interdisciplinary group work (Jin et al., 2018), and integrating VR into BIM education (Bouska and Heralova, 2019). Although these studies have addressed the collaborative or interdisciplinary nature of BIM through pedagogical activities, Pikas et al. (2013) suggested that BIM education could be upgraded from a single course to the program level. The inter-connectedness between courses within the same educational program, as suggested by Li et al. (2018), is yet to be adopted in the construction education with BIM as the vehicle. More recently, another study conducted at The University of Nottingham Ningbo China (Walker et. al., 2020) showed the significant impact of VR and BIM in the civil engineering program. In particular, it was identified the significance between VR/BIM in Civil Engineering as part of their studies to understand what a construction site looked like and moreover to run a number of different scenarios in a safe, integrated and comprehensive environment. This environment ensured successful completion of their studies incorporating a unique pedagogical approach that is linked to what is proposed in this study from a different angle, which focuses on the final stage capstone project in CM.

2.3. Individual perceptions towards BIM practice

Students' perceptions of BIM should be considered part of BIM education (Zou et al., 2019a). They would establish their perceptions of BIM course or project as part of their learning curve

(Jin et al., 2019; Zou et al., 2019a). Perceptions have a significant effect on human behavior (Dijksterhuis and Bargh 2001). Human behavior is one of the key issues in adopting information and communication technologies (Lu et al., 2015). These perceptions and follow-up behavior would form the learning and practice cycle in college graduates' professional career (Zou et al., 2019a). The individual perceptions towards BIM practice had been more widely studied among industry professionals (e.g., Sacks and Pikas, 2013; Lucas, 2017). Studying the perceptions of college students or BIM learners is also necessary (Jin et al., 2019). It is indicated from existing BIM-based studies (Eadie et al., 2013; Yalcinkaya and Singh, 2015; Oraee et al., 2017) that perceptions towards BIM should not only include technical aspects (e.g., interoperability), but also the managerial part of BIM. Managerial aspect shall be another core part of BIM (He et al., 2017), and could be incorporated in BIM education, for example, the collaborative group building design (Jin et al., 2018).

3. Research design

3.1. Options for students' final semester project

Students in their last semester of undergraduate CM study were asked to select one of the four options for their final project delivery, namely full BIM application in teamwork, group work focusing on construction planning/scheduling, individual work in take-off estimate, and an individual research dissertation. The group work in the former two options generally consisted of four or five members. Each group member had to demonstrate their fair individual contribution to the team project in their final presentation and project report. For example, in a five-person full BIM application group, the tasks were divided as (1) formwork and scaffolding construction plan assisted by BIM; (2) 3D modeling and virtual simulation of construction activities; (3)

scheduling and resource allocation in 5D BIM; (4) video/walkthrough/rendering and model checking in a cloud platform; and (5) 3D site planning and BIM implementation plan.

Construction planning/scheduling and take-off estimate were designed by the pedagogical staff as two options of partial BIM application. Regardless of the deliverable option, each individual was expected to spend around *320* hours on the final semester project. Using the subgroup of full BIM application as the example, this *320* hours excluded the one-week time for BIM software training and tutorial, and two-week field study as shown in Table 1. No other courses were assigned to students in the last semester. Students were expected to work on the project for four days and a half each week. The subgroup of full BIM application was expected to achieve the highest potential of the BIM, including 5D BIM for scheduling and quantity take-off, site planning, and linking BIM into other digital technologies (e.g., VR). Compared to the full BIM application subgroup, students choosing partial BIM applications might not achieve that high application level of BIM, but they were asked to perform certain hands-on work to compare the outcomes between manual and BIM-generated outputs. For example, students working on the take-off estimate were guided to perform their manual estimate and compared their manual outcome to what was generated from their BIM work.

Different from students working in a full or partial BIM application subgroup, those who chose the research dissertation might not utilize any BIM authoring tools, but perform a standard research methodology to address research questions in the CM domain. Students could choose their own research topics, either related to BIM or not. An example of the research dissertation leading to a journal article publication could be seen in Wu et al. (2019).

3.2. Questionnaire survey and statistical analyses

Following the completion of the final semester project in early June 2019, a follow-up questionnaire survey was designed to collect the feedback of CM students' perceptions of their project. The questionnaire survey was adopted to test the main research hypotheses:

- Students opting for different final project deliverable type would have consistent perceptions towards the effects of the project on their professional career;
- Students choosing different deliverable types could have consistent views on their BIM utilization in their final project;
- Students selecting different deliverable types could have consistent views on how their final semester project has enhanced their personal or professional skills.

The questionnaire was initiated by the course leader in the CM program at Fuzhou University, and peer-reviewed by other CM educators in other China and UK-based institutions. The questionnaire survey approach has been commonly adopted in the CM education-based research, especially following the end of pedagogical work. Examples of the questionnaire survey approach can be found in Han et al. (2019b), Zhou et al. (2019), and Jin et al. (2019). Before the formal questionnaire survey was sent to all senior year CM students, a pilot study was sent to other five students in early June. The feedback of students' in the pilot study was collected, leading to the finalized questionnaire to ensure that all questions asked were without vagueness. The questionnaire is attached in the Appendix. The questions covered students' background information, and their perceptions of BIM and their final semester project. The first two questions, as seen in the Appendix, asked their options from one of the four available deliverable types, and also their career decision right after completing their undergraduate study. The remaining four questions were based on the five-point Likert-scale format asking students to select a numerical score to describe their perceptions of BIM utilization on their project. For example, in Question 4, students were required to respond with a Likert score, from *1* being "The final year project that I completed is with little value to my career" to *5* meaning "The final year project that I completed is with great value to my career". The last two questions include multiple items related to BIM utilization and how the final semester project had enhanced different skills. Students' responses to these Likert-scale questions were analyzed in a variety of statistical methods.

Besides the descriptive statistical measurements (i.e., mean and standard deviation) of Likert-scale items, Cronbach's Alpha value (Cronbach, 1951), a commonly adopted measurement of internal consistency for multiple items in the same Likert-scale question, was utilized in this study. As recommended by DeVellis (2003), the overall Cronbach's Alpha value should be between *0.75* and *0.95* for Question 5 and Question 6 shown in the Appendix. An acceptable Cronbach's Alpha value means that a student who selects one numerical score to one item in the same question is likely to assign a similar score to others. Each item in Question 5 or Question 6 has an individual Cronbach's Alpha value, which is expected to be lower than the overall value. An individual value higher than the overall one would mean that the internal consistency increases if the given individual item is removed from Question 5 or 6. This would suggest that students had significantly different perception towards this given item as they would perceive other items.

Other statistical tests adopted in this study included Analysis of Variance (ANOVA) and the follow-up post-hoc analysis. These two tests were considered suitable for conducting subgroup analysis, i.e., subgroups of students opting for full BIM application, construction planning/scheduling, take-off estimate, or research dissertation. The subgroup analysis aimed to test whether there was a significant difference among subgroups of students in their perceptions towards each Likert-scale item or question. For each item or question, the null hypothesis was that the subgroups of students held consistent perception towards it. Based on a *5%* level of significance, an F value and corresponding p value would be computed using the statistical tool Minitab (2019). A p value lower than *0.05* would reject the null hypothesis and suggest the alternative hypothesis that subgroups had significantly different perceptions towards the given item. The procedure of conducting a parametric test (e.g., ANOVA) in the CM field can be found in some previous research (e.g., Tam, 2009; Wu et al., 2019). Accompanying ANOVA, the post-hoc test was implemented to identify where the significant differences occur among subgroups. The Fisher Individual, as suggested by Han et al. (2019a) and Wu et al. (2019), was adopted in this study to explore the potentially different perceptions between each pair of subgroups. The statistical software Minitab (2019) was used to define each subgroup with a "class" represented by an alphabet letter (e.g., A, B, C, etc.). For example, a subgroup tagged with "Class" A was suggested with more positive perception on the given item compared to the subgroup tagged by B and followed by C. These different "classes" were determined based on the subgroup's descriptive statistics, e.g., the mean value of the subgroup in perceiving the given Likert-scale item.

4. Display of deliverables of final semester undergraduate project

4.1. *Timetable and deliverables for the BIM group*

Typical deliverables of students' final semester project are displayed, depending on students' selection of deliverable type (i.e., full BIM application in a group project, construction planning/scheduling, take-off estimate, or research dissertation. The project lasts for *15* weeks in the spring semester of 2019. For the full BIM application group, the detailed timetable is displayed in Table 1. The typical network and workflow of a full BIM application team are illustrated in Fig.1.

<Insert Table 1 here>

The tasks and deliverable for other deliverable types might be different from Table 1. For example, students who chose a research dissertation as the deliverable would spend more effort on developing their research objectives, methodology, and implementing their research methods. They might not undergo the same process as the students involved in BIM-based projects. For those working on construction planning/scheduling or cost estimate, a similar workflow as shown in Table 1 was also applicable, for example, collecting and studying project drawings, BIM software tool tutorial, and modeling, etc. There were some differences for those focusing on construction planning/scheduling or cost estimate, for instance, manual calculation of formwork quantity, and other take-off estimates. Each team in the full BIM application and construction planning/scheduling was assigned a different project, with 2D CAD drawings and other documents provided. These projects were all high-rise buildings newly built or under construction in the metropolitan city of Fuzhou, China.

<Insert Fig.1 here>

As shown in Fig.1, the group work with full BIM application started from the 2D CAD drawings of the studied high-rise building project, 3D modelling in BIM, to 5D BIM for construction planning, cost control, and other site planning work. The 3D modeling process involved more than just “translation” from 2D CAD to 3D BIM, but also the interoperability of digital file format (e.g., IFC or Industry Foundation Class) among various digital tools. For example, the initial model in Autodesk Revit was also saved in different file formats (e.g., GTJ and GCL as shown in Fig.2).

<Insert Fig.2 here>

As shown in Fig.2., students on the same BIM project were guided to create digital models in different data formats. As reflected in their final project report, they did not only strengthen their modeling skill in a BIM environment with different digital formats but also gain the experience of how different data formats work in an interoperable way with follow-up tasks described in Fig.1, such as scheduling and site planning. The full BIM application team also created multiple families and uploaded into their models to develop the level of details as seen in Fig.3. One of the barriers encountered during BIM pedagogical work, as reflected by Jin et al. (2018), is the lack of families in the existing BIM library. Therefore, students had to create families to meet the project design or construction needs. On the other hand, researchers in this study believe that family creation to enrich the existing BIM library is an important part to train students with the technical BIM skills, which would be useful for their future work in the industry.

<Insert Fig.3 here>

Multiple family members in the BIM library were created in the digital platform. For example, the elevation shown in Fig.3-a) consists of a total of *26* different types of self-created window families, *15* different types of irregular-shaped windows, seven types of curtain wall families, and four types of integrated door-and-window components. All details of these building components were available in the group submission. Multiple other family members were created by the BIM group, such as the screw piling components as part of the foundation pit support system as shown in Fig.3-b).

The BIM group also further created the digital platform utilizing BIM and VR. As partially captured in Fig.4, the digital model of the project in various formats (e.g., GCL, GTJ) and 5D BIM platform were utilized to create six separate scenes in VR using the interactive and immersing features. Each scene was divided into dozens of observation points to enable users to observe various site details, e.g., tower cranes, elevators for construction, and heavy equipment, etc.

<Insert Fig.4 here>

Based on the original digital models in different formats, scheduling, site planning, 5D BIM, simulation, and walkthrough, the scenes were set up with the interface shown in Fig.4-a). Clicking the menu shown in the interface allowed users to perform different tasks, including model checking, queries of scheduling, and project-based construction education.

4.2. Groups or individuals working on other types of deliverables

For those working on construction scheduling/planning or take-off estimate, BIM might not be fully applied in their project work. For example, the digital platform integrated with BIM and VR as displayed in Fig.4 would not be generated. But they also started from transforming the given 2D CAD drawings into 3D digital models as described in Fig.1 and Fig.2. Similar to the full BIM application team, BIM was also applied in simulating construction activities, site planning, scheduling, and 5D BIM. Similar deliverables were visualized in the groups focusing on construction scheduling/planning as shown in Fig.5.

<Insert Fig.5 here>

However, differing from the subgroup of full BIM application, the subgroup of scheduling/planning had to perform the manual calculation and planning for scaffolding and formwork as shown in Fig.6-a). The manual calculation was later compared to the outcomes in BIM.

<Insert Fig.6 here>

Somehow similar to peers working on construction scheduling/planning, students working on take-off estimate also started from modeling in BIM, and compared their manual calculation of material take-off with the quantity generated from BIM. Their work also involved linking information between BIM authoring tool (e.g., Revit) and estimate software. Their manual calculation and modeling work included site work, concrete, masonry, reinforcement, and interior finish. Fig.7 displays examples of details of reinforcement together with the studied project.

<Insert Fig.7 here>

Table 2 demonstrates an example of comparing the quantity generated from the manual estimate and that from the BIM platform. It is seen that students focusing on take-off estimate also trained their modeling skill in BIM. More importantly, the explorative comparison of quantity take-off between manual work and BIM work provided in-depth experiential learning for students.

<Insert Table 2 here>

5. Follow-up questionnaire survey

By the end of June 2019, all *65* students responded to the questionnaire survey. After screening the raw survey data, one respondent's data was excluded due to the fact that the same scores were assigned to items under the same Likert-scale questions. Other three respondents' data were also excluded because they were incomplete. This screening process followed the procedure described in the study of Smits et al. (2017). The detailed subgroup distribution and the career options in the overall student sample is illustrated in Fig.8.

<Insert Fig.8 here>

The two different distributions shown in Fig.8 could be interlinked in the way that students who opted for research dissertation were more likely to pursue graduate study. Five out of the *13* students who decided to pursue graduate study were from the subgroup of a research dissertation, indicating that research dissertation should still be an option even without BIM involvement, especially for those interested in furthering their academic career. In comparison, those who opted for three other non-dissertation deliverable types were more likely to practice in the professional field right after finishing their undergraduate study.

5.1. *Students' perceptions of BIM and final semester project*

Students were asked of their perceptions towards BIM impacts on their final semester project, as well as their expectation of the final semester project's effect on their professional career. Based on the two five-point Likert scale questions, the ANOVA test results are presented in Table 3.

<Insert Table 3 here>

Significant differences were found in subgroups' perception of BIM. The subgroup of full BIM application held the most positive view of BIM's assistance to their projects, followed by the other two partial BIM application subgroups. It is understandable that the subgroup of research dissertation held significantly lower perceptions of BIM on their work, because they mostly did not apply the technical BIM skills. However, no significant difference was found in the expectation of their selected project deliverable type. All subgroups held positive expectations of their final semester project. It was inferred that the variety of project deliverable types should be maintained to allow students to select their own options at the last stage of their undergraduate study.

5.2. *Students' perceptions of BIM utilization in their final semester project*

Students were asked of their perceptions on how BIM had been utilized in different tasks within their final semester project. These BIM utilization are presented in the Appendix and Table 4. These tasks were corresponding to students' work in their deliverables. This Likert-scale question was designed to seek students' reflective thinking on the application level (i.e., from little application to a very high degree of implementation) of each BIM utilization in their project deliverable.

<Insert Table 4 here>

The Overall Cronbach's Alpha at *0.9573* indicated the high internal consistency of the ten BIM utilization related items. The overall value generally met the statistical requirement as suggested by Nunnally and Bernstein (1994). The ranking according to the mean values of each item in Table 4 showed that 3D modeling was the top-ranked utilization of BIM in project deliverables. This was consistent with other industry investigations in China's construction field (Jin et al., 2015; Liu et al., 2019) that the 3D modeling for visualization was the most widely adopted BIM feature. Similar to the findings released by Liu et al. (2019), other tasks (e.g., cost estimate and site management) had not been widely involved with BIM. Clash detection, although being considered a fundamental feature in BIM, had not been sufficiently involved in project deliverables. Clash detection, which was ranked bottom in Table 4, was also the only item with higher individual Cronbach's Alpha value than the overall value. It was inferred that students tended to have differed perception of clash detection as they would perceive other BIM utilization. Correspondingly, it is seen that the item of clash detection also had the lowest Item-total Correlation value, meaning that the item of clash detection has the lowest correlation with the remaining items in Table 4. The relatively high standard deviation of all items (i.e., higher than *1.000*) was due to the fact that students working on a research dissertation had a significantly lower chance of applying BIM. The subgroup analysis of students' perceptions is presented in Table 5.

<Insert Table 5 here>

It is seen in Table 5 that the full BIM application subgroup generally had the highest utilization level of BIM in their projects. In contrast, students working on a research dissertation had low or little BIM integration in their deliverable. Besides the *p* values to determine the significant differences among subgroups (especially the research dissertation subgroup with three other subgroups), the post-hoc analysis for each item in Table 5was also performed to further quantify the significance of the difference between each pair of subgroups. The post-hoc analysis in terms of Fisher pairwise comparisons defined each subgroup within an alphabet letter (e.g., A, B, and C). As seen in Table 5, post-hoc group tagged with A means that the corresponding subgroup had the highest level of BIM utilization in the given item, followed by B and C. For example, it is found that the full BIM application subgroup had the highest level of using BIM for 3D modeling. The other two partial BIM application subgroups had a similar utilization level for 3D modeling, falling into the post-hoc group B. In comparison, the subgroup of a research dissertation, tagged with C, had the lowest utilization of 3D modeling. Subgroups tagged with different alphabet letters indicate that they had a significantly different utilization level of BIM. However, sometimes a subgroup might be in a "fuzzy zone" in-between two post-hoc groups. For instance, the subgroup of take-off estimate was tagged by two post-hoc groups (i.e., A&B). In this case, students who selected take-off estimate had lower utilization of clash detection compared to their peers in the full BIM subgroup, but higher utilization compared to their peers in construction scheduling/planning. Nevertheless, these differences were less significant as the take-off estimate subgroup fell into the "fuzzy zone". By tagging each subgroup with a post-hoc group letter, it was found that the two partial BIM application subgroups might also have significantly different utilization levels of certain BIM items, including model checking, formwork & scaffolding planning, scheduling, site planning, and construction work breakdown.

5.3. *Students' perceptions of the effects of the final year project*

The same statistical procedure was adopted to analyze the data for the Likert-scale question regarding students' perceptions of how their final semester project enhanced their various skills. Students were made clear of the definition of each skill listed in the Appendix and Table 6. For example, teamwork did not necessarily only occur in the subgroups of full BIM application or construction planning/scheduling where students worked in a group, but also two other subgroups working on individual deliverables. For example, students might work on different parts of take-off estimate for the same highly-complex project. The BIM operation skill mostly referred to students' capability in adopting BIM software package; the hands-on skill referred more to hardware, e.g., setting up BIM platform integrating VR devices in the digital lab of Fuzhou University. Besides these main skills listed in Table 6, students were also asked to list any other skills that had been enhanced according to their own reflection. A few students mentioned that the last semester project also significantly enhanced their critical thinking or independent thinking.

<Insert Table 6 here>

Generally, students held positive perceptions of their final semester project in enhancing their multiple skills, especially their self-learning skill, professional knowledge, hands-on skill, and BIM operation skill, whose mean scores were all over *4.000*. The overall Cronbach's Alpha at *0.8119* met the internal consistency requirement, meaning that a student chose a numerical score to one item would be likely to assign a similar score to other items in Table 6, except the item of BIM operational skill. The individual Cronbach's Alpha of that item at *0.8160* higher than the overall value and the lowest Item-total Correlation indicates that students had more varied perceptions towards their BIM operation skill. That could be explained that the subgroup of the research dissertation did not have much practice in operating BIM. The detailed subgroup analysis is presented in Table 7.

<Insert Table 7 here>

Extending from Table 6 regarding BIM operation skill, the high F value and p value lower than *0.05* in Table 7 suggest the significant differences among subgroups' perceptions. The post-hoc analysis identifies that the difference came from the subgroup of the research dissertation. Instead, the other three subgroups involving either full or partial BIM application held consistent views on how their BIM operation skills had been enhanced through the final semester project. The high mean scores from these three subgroups (i.e., all above *4.000*) show students' highly positive view on their BIM operation skill. Other two skills were also perceived by students with significant differences: teamwork skill and hands-on skill. As evidenced by the post-hoc analysis, the subgroups of full BIM application and construction planning/scheduling, who worked in a group project environment, perceived that they had more enhancement in teamwork skill. The significantly differed views on the enhancement of hands-on skill could also be found among the four subgroups. It is seen that students from the full BIM application subgroup perceived themselves with the most enhancement of hands-on skill, possibly because they had more opportunities of setting up hardware devices (e.g., VR headset) and linking them to BIM software tools. The subgroups of construction planning/scheduling and research dissertation perceived significantly lower enhancement, probably because that their work was more on digital modeling, manual calculation, site investigation, data collection and analysis, and academic writing.

6. Discussion

Findings from this study mainly come from two parts, namely the showcase of students' BIM work and the follow-up questionnaire survey. Students from subgroups of full BIM application or partial BIM usage (i.e., construction planning/scheduling and take-off estimate) delivered their final semester project in a variety of digital files (e.g., videos, digital files in different BIM authoring tools, and project report). Their project reports generally contained reflective thinking linked to their end-of-project oral presentation. For example, one team from the construction planning/scheduling subgroup reflected that although lots of manual modeling work was required to add details from 2D CAD into 3D models in Revit, this time-consuming process trained their modeling skills. This process also enhanced their skills when transforming building information into other data formats (e.g., GCL). They reported that this modeling process improved their appraisal of information interoperability and the need for better integration among different digital tools. In the case of the take-off estimate work, a student might find a significant difference (e.g., over 10% difference) between their manual estimate and the quantity generated from BIM. He or she had to review both parts of the estimate to explore causes of the differences, and also to minimize the differences. Some typical causes identified included: errors of omitting some quantities of building components (e.g., concrete beams), and the information gap between the original 2D CAD drawing and the 3D BIM. These self-checking and critical thinking during the *15*-week project were believed to have enhanced their multiple skills (e.g., self-learning) as described in their reflective reports.

Various options of final year project deliverables should be provided for students to select, depending on their own interests and career plan. For example, students more interested in developing their research career might be prone to select the research dissertation type. Overall, all different deliverable types could lead to students' consistently positive perceptions or expectations towards their project and their professional career.

The current study followed the recommendation of Pikas et al. (2013) by extending the BIM-embedded construction education from the earlier single course to the final stage capstone project. The design of the BIM-driven capstone project incorporated the undergraduate educational guide proposed by Chickering and Gamson (1987), specifically, the collaborative learning enhanced by BIM as the digital platform, and timely feedback from the academic staff to student groups. Bloom's Taxonomy (Bloom, 1956) was further extended by addressing students' different levels of learning. Students applied their previous knowledge and understanding of BIM into the real-world project practice, and further developed their reflective thinking in their project report and the follow-up questionnaire survey.

The questionnaire survey capturing students' perceptions of BIM utilization within their own project might seem rhetorical. For example, it might be argued that apparently the full BIM application subgroup would have the highest utilization of BIM and the research dissertation subgroup was expected to have the lowest utilization. However, the questionnaire survey served as the feedback tool to capture students' reflective thinking on BIM, and to confirm the pre-assumptions regarding BIM application in different subgroups. Besides the confirmative investigation through the questionnaire survey, the explorative study was also involved, including the ranking of different BIM utilization. The further post-hoc analysis revealed the significance level of differences between each pair of subgroups, e.g., between the two different partial BIM application subgroups.

Student feedback on BIM utilization and skill enhancement could be used to update the future final semester pedagogical delivery. Specifically, depending on their skill development needs, career needs, and personal interests in different BIM utilization, students could be guided with the deliverable option that best fit their needs at the last stage of their CM undergraduate study. Since these various options for CM students just started in the recent two years, the current study only targeted students newly finishing their final semester project. As indicated by Li et al. (2018) who suggested to also study the longer-term effects of a newly created course on college graduates' engineering career, the final semester projects' effects on CM graduates' career development could be tracked by targeting the alumni who have already been working in the industry.

The current pedagogical study would lead to more integration of BIM and other digital technologies (e.g., Augmented Reality or AR) for continuing the update of educational activities. More research-informed teaching could be adopted in the future BIM education crossing different years of the CM undergraduate curriculum, for example, BIM integrated with AR to capture construction site progress (Kim et al., 2018), BIM and Geographic Information Systems for increasing the automation level (Kang and Hong, 2018), and sensor deployment in BIM (Cho, et al., 2018), etc. The current study motivates more future educational activities addressing BIM maturity levels (The UK Government Construction Strategy Board, 2011), especially the transition from BIM Level 2 to Level 3 following the guide of the UK Government's Department for Business, Innovation and Skills (2016). More research-informed teaching (Healey, 2005) can be performed in BIM-embedded construction programs, for example, BIM should be considered in the bigger picture of digitalization by being linked to a variety of digital technologies such as AR or drone. The information exchange between BIM and other digital technologies (e.g., VR in this study) can motivate students to investigate the interoperability issue when transforming information from one digital tool to another.

7. Conclusion

This BIM pedagogical study can be divided into two parts, namely demonstration of student project deliverable incorporating BIM, and the follow-up questionnaire survey to investigate students' perceptions on the effects of BIM adoption and their final year project. Students were given four different options in their last semester project, namely the subgroup of full BIM application, two subgroups of partial BIM usage (i.e., construction planning/scheduling or take-off estimate), and a research dissertation. Examples of student deliverables from different subgroups were demonstrated to show how BIM had been adopted as the digital platform to assist a variety of construction tasks (e.g., 3D site planning). The full BIM application teamwork was demonstrated with their *15*-week timetable and collaborative working. Various data files (e.g., IFC) were displayed to showcase the issue of information interoperability. The partial BIM application subgroup demonstrated their explorative comparison between the manual work and BIM-generated work, e.g., the difference of quantity take-off between manual estimate and BIM-generated output. Students also demonstrated their critical thinking of difficulties and gaps identified through their end-of-semester oral presentation and project reports.

Research hypotheses were initiated to test whether the different deliverable options would affect students' perceptions of the final semester project and their future career. The questionnaire survey revealed that significant differences of subgroup perceptions did not only occur between the subgroup of research dissertation and other subgroups, but also among the BIM application subgroups. The two partial BIM application subgroups also had significant differences in BIM utilization, including model checking, formwork & scaffolding planning, scheduling, site planning, and construction work breakdown. For instance, the full BIM application subgroup had the similar utilization level as the construction scheduling/planning subgroup did in 3D site planning, but with a significantly higher level of BIM utilization compared to the subgroup of take-off estimate. The questionnaire survey also inferred that not all BIM features were consistently applied to support tasks in students' project deliverables. Specifically, clash detection, as one of the commonly utilized BIM features, had not been sufficiently used in their final semester project. Future pedagogical work in adopting BIM for student capstone project could consider how to better achieve comprehensive coverage of different BIM utilization, especially for the full BIM application group. Regardless of the project deliverable types, the final semester project was perceived consistently positive in enhancing their self-directed learning skills. Other skills including professional knowledge, research skill, and innovation skill were also consistently perceived by students as been enhanced throughout the semester-long project. However, significant differences in perceptions were found on how the project has enhanced their BIM operation skill, teamwork skill, and hands-on skill. It was found that students from the three BIM-related subgroups had a consistent view of their BIM operation skill enhancement. But the full BIM application subgroup had significantly more positive perception on the hands-on skill enhancement, possibly due to the fact they had more practice in linking software and hardware devices (e.g., BIM and VR).

The current study contributed to the body of knowledge in BIM education both theoretically and practically. Theoretical guides in the higher education was incorporated in this study to demonstrate that BIM education could address different levels of students' learning by linking prior single courses into the final stage project. Latest industry guides such as BIM maturity level and information exchange were considered in student deliverables assisted by BIM. Based on these theoretical and industry guides, more future education work could emphasize research-informed teaching, for instance, BIM integrated with other digital technologies (e.g., augmented reality) in the bigger picture of digitalization. Practically, insights for the last stage CM student project (e.g., last semester project in this case study) can be provided, including the variety of deliverable types as options for students by considering their interests and career development needs. For example, final year undergraduate students who decide to pursue graduate study might select a research dissertation, and students planning to work in the practical field might choose other project-based types. Students could also be given the option of working in a collaborative team approach or focusing more as an individual. Different deliverable types or options could meet students' individual needs and lead to consistently positive feedback on the effects of the last stage project. Some suggestions could be provided to update the future pedagogical activities, for example, clash detection, as a basic BIM feature, could be better utilized in assisting the design and pre-construction management.

The current study is limited to investigate students' self-perception of the effects of BIM-related deliverable type, without reaching further their future career development. Future research work could collect students' feedback after they have been working in the industry for a certain period of time. As the continued learning and practice curve, students' career growth could be tracked by evaluating their future employers' perceptions of students' adoption of information and communication technologies.

Acknowledgement

This paper was supported by Science and Technology Development Program on Traffic and Transportation in Fujian Province [Grant No.: 201415], Educational Commission of Fujian

Province, China [Grant No.: JT180046]. The authors would also like to acknowledge the financial support from the 2018 First-class Undergraduate Teaching Reformation and Innovation Program at Fuzhou University.

References

Bland, J. and Altman, D. (1997). “Statistics notes: Cronbach's alpha.” BMJ. 314:275. DOI: 10.1136/bmj.314.7080.572

Bloom, B. S. (1956), “Taxonomy of Educational Objectives, the Classification of Educational Goals – Handbook I: Cognitive domain”, New York, McKay, pp.16.

Bouska, R., and Heralova, R.S. (2019). “Implementation of virtual reality in BIM education.” Advances and Trends in Engineering Sciences and Technologies III- Proceedings of the 3rd International Conference on Engineering Sciences and Technologies, 331-336. VysokéTatry, Slovakia; 12-14 September 2018. https://www.crcpress.com/Advances-and-Trends-in-Engineering-Sciences-and-Technologies-III-Proceedings/Ali-Platko/p/book/9780367075095.

Chen, W., Xu, Y., Jin, R., and Wanatowski, D. (2019). “Text Mining–Based Review of Articles Published in the Journal of Professional Issues in Engineering Education and Practice.”*J. Prof. Issues Eng. Educ. Pract.*, 145(4), 06019002. DOI: 10.1061/(ASCE)EI.1943-5541.0000425. DOI:10.1061/(asce)ei.1943-5541.0000425.

Chickering, A. W., & Gamson, Z. F. (1987), “Seven principles for good practice in undergraduate education. American Association for Higher Education & Accreditation Bulletin”, *March*, 39 (7), pp. 3-7. Available from www.aahea.org/bulletins/articles/sevenprinciples1987.htm [Accessed 11 December 2017]

Cho, C., Park, J., and Kim, K. (2018). "Automated and Optimized Sensor Deployment using Building Models and Electromagnetic Simulation." *KSCE J. Civ. Eng.*, 22(12), 4739-4749. DOI: 10.1007/s12205-018-1150-z.

Cronbach, L. J. (1951). “Coefficient alpha and the internal structure of tests.”*Psychometrika.*,16 (3), 297-334. DOI:10.1007/BF02310555

DeVellis, R. F. (2003). “Scale development: theory and applications.”2nd Ed., SAGE Publications, Inc., Thousand Oaks, CA. DOI:10.1016/0886-1633(93)90012-e

Dijksterhuis, A., and Bargh, J. A. (2001). “The perception-behavior expressway: Automatic effects of social perception on social behavior.” *Adv. Exp. Social. Psychol.*, 33, 1–40. DOI: 10.1016/S0065-2601(01)80003-4

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013). “BIM implementation throughout the UK construction project lifecycle: an analysis.” *Autom. Constr.*, 36,145-151. DOI:10.1016/j.autcon.2013.09.001

Han, Y., Feng, Z., Zhang, J., Jin, R., and Aboagye-Nimo, E. (2019a). “Employees’ safety perceptions of site hazard and accident scenes.” *J. Constr. Eng. Manage*. 145(1): 04018117. DOI:10.1061/(asce)co.1943-7862.0001590.

Han, Y., Jin, R., Wood, H., and Yang, T. (2019b). "Investigation of Demographic Factors in Construction Employees’ Safety Perceptions." *KSCE J. Civ. Eng.*, 23(7), 2815-2828. DOI: 10.1007/s12205-019-2044-4.

He, Q., Wang, G., Luo, L., Shi, Q., Xie, J., and Meng, X., 2017. “Mapping the managerial areas of Building Information Modeling (BIM) using scientometric analysis.” *Int. J. Proj. Manag.* 35, 670–685. DOI:10.1016/j.ijproman.2016.08.001

Healey, M. (2005), “Linking research and teaching exploring disciplinary spaces and the role of inquiry-based learning”, in Barnett, R. (ed.) Reshaping the university: new relationships between research, scholarship and teaching, Maidenhead: McGraw-Hill/Open University Press, p30-42.

Jin, R., Tang, L., and Fang, K. (2015). “Investigation into the current stage of BIM application in China’s AEC industries,” in BIM 2015 First International Conference on Building Information Modelling (BIM) in Design, Construction and Operations, *WIT Transactions on The Built Environment*, 149 (2015), 493-503. DOI:10.2495/bim150401

Jin, R., Yang, T., Piroozfar, P., Kang, B.G, Wanatowski, D., and Hancock, C.M. (2018). “Project-based pedagogy in interdisciplinary building design adopting BIM.” *Engineering, Construction and Architectural Management*, 25(10), 1376-1397. DOI:10.1108/ecam-07-2017-0119

Jin, R., Zou, P.X.W., Bo, L., Piroozfar, P., and Painting, N. (2019). “Comparisons of students’ perceptions on BIM practice among Australia, China and U.K.” *Engineering, Construction and Architectural Management*. 26(9), 1899-1923. DOI: 10.1108/ECAM-07-2018-0275. DOI:10.1108/ecam-07-2018-0275

Kang, T. W., and Hong, C. H. (2018). "IFC-CityGML LOD mapping automation using multiprocessing-based screen-buffer scanning including mapping rule." *KSCE J. Civ. Eng.*, 22(2), 373-383. DOI: 10.1007/s12205-017-0595-9.

Kim, H. S., Kim, S. K., Borrmann, A., and Kang, L. S. (2018). "Improvement of Realism of 4D Objects Using Augmented Reality Objects and Actual Images of a Construction Site." *KSCE J. Civ. Eng.*, 22(8), 2735-2746. DOI: 10.1007/s12205-017-0734-3.

Kim, J. (2011). “Use of BIM for effective visualization teaching approach in construction education.” *J. Prof. Issues Eng. Educ. Pract.*, 138(3), 214-223. DOI: 10.1061/(asce)ei.1943-5541.0000102.

Kim, J. I., Koo, B., Suh, S., and Suh, W. (2016a). "Integration of BIM and GIS for formal representation of walkability for safe routes to school programs." *KSCE J. Civ. Eng.*, 20(5), 1669-1675. DOI: 10.1007/s12205-015-0791-4.

Kim, S., Park, C. H., and Chin, S. (2016b). "Assessment of BIM acceptance degree of Korean AEC participants." *KSCE J. Civ. Eng.*, 20(4), 1163-1177. DOI: 10.1007/s12205-015-0647-y.

Koo, B., Shin, B., and Lee, G. (2017). "A cost-plus estimating framework for BIM related design and engineering services." *KSCE J. Civ. Eng.*, 21(7), 2558-2566. DOI: 10.1007/s12205-017-1808-y.

Lee, P. C., Xie, W., Lo, T. P., Long, D., and Tang, X. (2019). "A Cloud Model-based Knowledge Mapping Method for Historic Building Maintenance based on Building Information Modelling and Ontology." *KSCE J. Civ. Eng.*, 23(8), 3285-3296. DOI: 10.1007/s12205-019-2457-0.

Lee, S., and Yu, J. (2017). "Discriminant model of BIM acceptance readiness in a construction organization." *KSCE J. Civ. Eng.*, 21(3), 555-564. DOI: 10.1007/s12205-016-0555-9.

Li, B., Zhang, M., Jin, R., Wanatowski, D., and Piroozfar, P. (2018). “Incorporating woodwork fabrication into the integrated teaching and learning of civil engineering students.” *J. Prof. Issues Eng. Educ. Pract.*, 144(4): 05018007. DOI: 10.1061/(ASCE)EI.1943-5541.0000377.

Liu, N., Ruan, L., Jin, R., Chen, Y., Deng, X, and Yang, T. (2019). “Investigation of individual perceptions towards BIM Implementation-a Chongqing case study.” *Engineering, Construction and Architectural Management*. 26(7), 1455-1475. DOI: 10.1108/ecam-08-2018-0342.

Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R., and Le, Y. (2015). “Information and communication technology applications in architecture, engineering, and construction organizations: a 15-year review.” *J. Manage. Eng.,*31(1), A4014010 DOI: 10.1061/(asce)me.1943-5479.0000319.

Lucas, J. D. (2017). “Identifying Learning Objectives by Seeking a Balance between Student and Industry Expectations for Technology Exposure in Construction Education.” *J. Prof. Issues Eng. Educ. Pract.*, 143(3), 5016013. DOI: 10.1061/(asce)ei.1943-5541.0000318.

Ma, J., Ma, Z., and Li, J. (2017). "An IPD-based incentive mechanism to eliminate change orders in construction projects in China." *KSCE J. Civ. Eng.*, 21(7), 2538-2550. DOI: 10.1007/s12205-017-0957-3.

Mathews, M. (2013). “BIM collaboration in student architectural technologist learning.” *AEI 2013*, 1-13. DOI:10.1061/9780784412909.001.

Minitab (2019). “Minitab 19.” Available via <https://www.minitab.com>, accessed on 28 May 2019.

Nawari, N.O. (2015). “The role of BIM in teaching structural design.” *Structures Congress,* 2622-2631. DOI: 10.1061/9780784479117.227

Nunnally, L. and Bernstein, L. (1994).“Psychometric theory.”McGraw-Hill, Inc., New York. http://www.sciepub.com/reference/198844.

Oraee, M., Hosseini, M.R., Papadonikolaki, E., Palliyaguru, R., and Arashpour, M. (2017). “Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review.” *Int. J. Proj. Manag.,* 35, 1288–1301. DOI: 10.1016/j.ijproman.2017.07.001.

Pikas, E., Sacks, R., and Hazzan, O. (2013). “Building information modeling education for construction engineering and management. II: procedures and implementation case study.” *J. Constr. Eng. Manage.,*139(11). DOI: 10.1061/(asce)co.1943-7862.0000765

Sacks, R., and Pikas, E. (2013). “Building information modeling education for construction engineering and management. I: industry requirements, state of the art, and gap analysis.” *J. Constr. Eng. Manage*.,139(11). DOI: 10.1061/(asce)co.1943-7862.0000759

Santos, R., Costa, A.A., and Grilo, A. (2017). “Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015.”*Autom. Constr.*, 80, 118–136. DOI: 10.1016/j.autcon.2017.03.005

Sharag-Eldin, A., and Nawari, N.O. (2010). “BIM in AEC education.” *Structures Congress,* 1676-1688. DOI: 10.1061/41130(369)153

Shelbourn, M, Macdonald, J, McCuen, T, and Lee, S. (2017). “Students' perceptions of BIM education in the higher education sector: a UK and US perspective.” *Industry & Higher Education*, 31 (5), 293-304. DOI: 10.1177/0950422217725962

Smits, W., Buiten, M.V., and Hartmann, T. (2017). “Yield-to-BIM: impacts of BIM maturity on project performance.”*Build. Res.Inf.*, 45(3), 336-346. DOI: 10.1080/09613218.2016.1190579

Solnosky, R.L., and Parfitt, M.K.(2015). “A curriculum approach to deploying BIM in Architectural Engineering.” *AEI 2015*, 651-662. DOI:_10.1061/9780784479070.057

Suwal, S., P. Jäväjä, and J. Salin. 2014. "BIM education: Implementing and reviewing "OpeBIM"—BIM for teachers." *In Proc., Computing in Civil and Building Engineering*, 2151–2158. Reston, VA: ASCE. DOI: 10.1061/9780784413616.267.

Tam, V.W.Y. (2009). "Comparing the implementation of concrete recycling in the Australian and Japanese construction industries." *J. Clean. Prod.,* 17(7), 688-702. DOI: 10.1016/j.jclepro.2008.11.015.

Tang, L., Jin, R., and Fang, K. (2015). "Launching the innovative BIM module for the architecture and built environment programme in China." *WIT Transactions on The Built Environment*. 149, 145-156. DOI: 10.2495/bim150131.

Underwood, J. and Ayoade, O. (2015). "Current Position and Associated Challenges of BIM Education in UK Higher Education." BIM Academic Forum, Manchester.

UK Government Construction Strategy Board (2011), "A report for the Government Construction Client Group", London: BIM Task Group.

UK Government's Department for Business, Innovation and Skills (2016), "Launch of Digital Built Britain", Available via <https://www.gov.uk/government/organisations/innovate-uk>, accessed on Apr 29th, 2019.

Walker J., Towey, D., Pike, M., Wei, S., Kapogiannis G., and Elamin, A.(2019)."Incorporating Pedagogical Theory into VR to Teach Civil Engineering." International Conference on Open and Innovative Education, Hong Kong, China. http://icoie2019.ouhk.edu.hk/.

Walker, J., Towey, D., Wei, S., Pike, M., Kapogiannis, G., and Elamin, H. (2020) Developing a Pedagogical Photoreal Virtual Environment to Teach Civil Engineering. *Journal of Interactive Technology and Smart Education,* In press.

Wu, P., Xu, Y., Jin, R., Lu, Q., Madgwick, D., and Hancock, C. (2019). "Perceptions towards Risks involved in off-site construction in the integrated design & construction project delivery." *J. Clean. Prod*. 213, 899-914. DOI: 10.1016/j.jclepro.2018.12.226

Yalcinkaya, M., and Singh, V. (2015). "Patterns and trends in building information modeling (BIM) research: a latent semantic analysis." *Autom. Constr.*, 59, 68–80. DOI: 10.1016/j.autcon.2015.07.012

Zhang, J., Xie, H., and Li, H. (2019). "Improvement of students problem-solving skills through project execution planning in civil engineering and construction management education." *Engineering, Construction and Architectural Management*. In Press. DOI: 10.1108/ecam-08-2018-0321.

Zhao, D., McCoy, A. P., Bulbul, T., Fiori, C., and Nikkhoo, P. (2015). "Building collaborative construction skills through BIM-integrated learning environment." *International Journal of Construction Education and Research*, 11(2), 97-120. DOI: 10.1080/15578771.2014.986251

Zheng, L., Chen, K., and Lu, W. (2019). "Bibliometric Analysis of Construction Education Research from 1982 to 2017."*J. Prof. Issues Eng. Educ. Pract.*, 145(3), 04019005. DOI: 10.1061/(ASCE)EI.1943-5541.0000412.

Zhou, Q., Deng, X., Jin, R., and Chang, T. (2019). "Analyzing the Key Drivers of Contractors' Temporary Competitive Advantage in the Competition of International High-speed Rail Projects." *KSCE J. Civ. Eng.*, 23(11), 4579-4591. DOI: 10.1007/s12205-019-0602-4.

Zou, P.X.W., Xu, X., Jin, R., Painting, N., and Li, B. (2019a). "AEC students' perceptions towards BIM practice-a case study of Swinburne University of Technology." *J. Prof. Issues Eng. Educ. Pract.*,145(3): 05019002. DOI: 10.1061/(asce)ei.1943-5541.0000410.

Zou, Y., Kiviniemi, A., Jones, S. W., and Walsh, J. (2019b). "Risk Information Management for Bridges by Integrating Risk Breakdown Structure into 3D/4D BIM." *KSCE J. Civ. Eng.*, 23(2), 467-480. DOI: 10.1007/s12205-018-1924-3.

Appendix: Questionnaire survey to students following their final semester project

1. Please select your final semester project deliverable type. (Single choice)
   A. Full BIM application; B. Construction planning/scheduling; C. Take-off estimate; D. Research dissertation
2. Which of the following options best describes your job after finishing your undergraduate study?
   A. Real estate; B. Contractor; C. Construction authority; D. Consultancy; E. Design firm; F. Pursuing graduate study; G. Undecided yet; H. Others__________
3. How would you perceive the impact of BIM on your final semester project? Please choose one of the five numerical scores given below.
   (1) Little impact; (2) A little help by adopting BIM; (3) Neutral; (4) BIM is helpful on my final year project; (5) BIM is very useful on my project
4. Which of the following statements best described your expectation of the final year project on your future professional career?
   (1) The final year project that I completed is with little value to my career;
   (2) The final year project that I completed is with limited value to my career;
   (3) The final year project that I completed is with some value to my career;
   (4) The final year project that I completed is valuable to my career;
   (5) The final year project that I completed is with great value to my career
5. Please select one of the five numerical values to rank how BIM has been utilized in each of the following activities in your final semester project. (1: Little or no application; 2: Limited application;3. Some application; 4. High degree of implementation; 5. Very high degree of implementation)

Activity	BIM utilization level (please select a number from 1 to 5)
3D modeling	
Automatic generation of quantities	
Information exchange in an interoperable manner	
Model checking in the cloud platform	
Clash detection	
Planning of formwork and scaffolding	
Assisting manual calculation	
Scheduling of construction activities	
3D site planning	
Construction work breakdown and resource allocation	

6. Please select one of the five numerical values to rank how each of the following personal skills has been enhanced throughout the final semester project. (1: Little or no enhancement; 2: Limited enhancement;3. Some enhancement; 4. Significant enhancement; 5. Very significant enhancement)

Activity	Level of enhancement (please select a number from 1 to 5)
Professional knowledge in the CM discipline	
BIM operation skill	
Self-learning and teaching skill	
Teamwork skill	
Research skill	
Innovation skill	

Hands-on skill	
Others, please specify____________________	

Table 1. Timetable of the *15*-week final semester undergraduate project

Week	Content/tasks	Deliverable(s)
1	Induction of the final semester project; collecting project drawings in 2D CAD format and other project documents; studying the collected drawings and documents in order to become familiar of theproject; starting proposing construction plan, schedule, or other construction issues	
2	BIM software tool training and tutorial (e.g., China's domestic GCL developed by Glondon); starting creating the digital model for the studied project; BIM adoption in formwork and scaffolding design; BIM assistance in calculating slope reinforcement, scaffolding and formwork	
3-4	Field trip and study on project site	
5-7*	Construction planning by defining work breakdown structures; adopting BIM to conduct take-off estimate; utilizing digital tools to assist scheduling; completing the thesis opening report	Submission of site study report from the field trip; submission of thesis opening report
7-8*	Determining the durations of each construction activity; establishing the scheduling network (e.g., Gantt Chart);	Submission of the mid-term progress report;
9-10	Establishing the resource allocation plan, e.g., equipment use, labor, materials, etc; establishing the detailed work breakdown plan; adopting BIM authoring tools (e.g., Autodesk Revit) to complete construction simulation and walkthrough	
11-12	Completing 4D construction simulation, including the simulation video corresponding to construction scheduling	
13	Establishing construction quality assurance and quality control plan; establishing construction safety and site housekeeping plan; designing and visualizing the 3D site planning; establishing the project organization network and subcontracting contracts; writing up the construction manual and checking the prior work	
14	Initially completed work being checked and commented by the academic supervisor; oral presentation and defence of the final semester project	
15	Submission of project portfolio, including report/essay/dissertation, digital files (e.g., video, BIM files), and other documents.	

Note: the week periods of 5-7 and 7-8 have some overlapping because the tasks of Week 5-7 were expected to be completed before the middle of Week 7.

Table 2. An example of comparison between manual quantity estimate and BIM-generated estimate

	Manual calculation /m^3	BIM-generated estimate /m^3	Difference
Shear wall	1455.48	1533.48	5.1%
Masonry wall	1202.30	1246.04	3.5%
Beams and slabs	1368.15	1478.33	7.4%
Foundation	589.30	616.35	4.4%

Table 3. ANOVA results for student subgroups in their perception/expectation of BIM and final year project

Subgroup	**Statistics of perception of BIM impact on the final semester project**		**Statistical comparison**		**Statistics of expectation of the final semester project**		**Statistical comparison**	
	Mean	Std.[1]	*F* value	*p* value	Mean	Std.*	*F* value	*p* value
Full BIM application	4.579	0.769	**25.54**	**0.000*****	4.105	0.875	1.10	0.356
Construction scheduling/planning	4.000	1.155			3.600	0.843		
Take-off estimate	3.600	0.995			4.150	0.813		
Research dissertation	1.667	0.778			3.833	1.030		

Note: 1.Std. stands for standard deviation; 2. The *p* value lower than *0.05* suggested that there is a significant difference among the subgroups' perceptions

Table 4. Overall sample analysis in the question of BIM utilization in their final semester project (Overall Cronbach's Alpha = *0.9573*)

BIM utilization	Mean	Std.	Ranking	Item-total Correlation	Cronbach's Alpha
3D modeling	4.017	1.295	1	0.7991	0.9535
Automatic generation of quantities	3.717	1.342	2	0.7010	0.9570
Information exchange in an interoperable manner	3.700	1.357	3	0.8901	0.9499
Model checking in the cloud platform	3.350	1.482	9	0.7663	0.9547
Clash detection	2.700	1.555	10	0.6681	**0.9590***
Planning of formwork and scaffolding	3.550	1.556	5	0.8588	0.9508
Assisting manual calculation	3.583	1.357	4	0.8092	0.9530
Scheduling of construction activities	3.450	1.545	7	0.8888	0.9495
3D site planning	3.500	1.578	6	0.8879	0.9496
Construction work breakdown and resource allocation	3.383	1.552	8	0.8719	0.9503

*: An individual Cronbach's Alpha value higher than the overall value suggests that survey participants

Table 5. Statistical results for subgroup analysis of students to the question of BIM utilization in their final semester project

Subgroup / BIM utilization	**Full BIM application**		**Construction planning/ scheduling**		**Take-off estimate**		**Research dissertation**		**Statistical comparison**	
	Mean	Post-hoc group	Mean	Post-hoc group	Mean	Post-hoc group	Mean	Post-hoc group	*F* value	*p* value
3D modeling	4.889	A	4.100	B	4.300	B	2.167	C	**24.76**	**0.000***
Automatic generation of quantities	4.222	A	3.500	A	4.250	A	2.250	B	**9.81**	**0.000***
Information exchange in an interoperable manner	4.526	A	4.100	A&B	3.550	B	2.333	C	**9.98**	**0.000***
Model checking in the cloud platform	4.316	A	2.600	B	3.600	A	2.083	B	**9.66**	**0.000***
Clash detection	3.421	A	2.100	B	2.600	A&B	2.083	B	2.72	0.053
Smart planning of formwork and scaffolding	4.667	A	4.100	A	3.050	B	2.250	B	**10.29**	**0.000***
Assisting manual calculation	4.263	A	3.600	A	3.750	A	2.250	B	**7.46**	**0.000***
Scheduling of construction activities	4.722	A	4.000	A	2.800	B	2.167	B	**14.00**	**0.000***
3D site planning	4.833	A	4.100	A	2.700	B	2.333	B	**14.69**	**0.000***
Construction work breakdown and resource allocation	4.737	A	3.700	B	2.700	C	2.167	C	**15.01**	**0.000***

* A *p* value lower than *0.05* indicates significant differences of perceptions of students from different subgroups

Table 6. Overall sample analysis of students' perceptions of their final semester project's effects (Overall Cronbach's Alpha = *0.8119*)

Effect	Mean	Std.	Ranking	Item-total Correlation	Cronbach's Alpha
Professional knowledge in the CM discipline	4.344	0.680	2	0.5712	0.7895
BIM operation skill	4.115	1.185	4	**0.4275**	**0.8160***
Self-directed learning skill	4.459	0.673	1	0.6114	0.7850
Teamwork skill	4.066	1.031	5	0.6344	0.7711
Research skill	3.787	1.127	6	0.4825	0.8024
Innovation skill	3.770	1.055	7	0.6199	0.7739
Hands-on skill	4.230	0.864	3	0.6500	0.7717

*: An individual Cronbach's Alpha value higher than the overall value suggests that survey participants

Table 7. Statistical results for subgroup analysis of students' perceptions of their final semester project's effects

Subgroup / BIM utilization	Full BIM application		Construction planning/ scheduling		Take-off estimate		Research dissertation		Statistical comparison	
	Mean	Post-hoc group	Mean	Post-hoc group	Mean	Post-hoc group	Mean	Post-hoc group	*F* value	*p* value
Professional knowledge in the CM discipline	4.316	A	4.200	A	4.400	A	4.417	A	0.24	0.867
BIM operation skill	4.737	A	4.300	A	4.450	A	2.417	B	**21.35**	**0.000***
Self-directed learning skill	4.632	A	4.100	B	4.450	A&B	4.500	A&B	1.41	0.249
Teamwork skill	4.790	A	4.300	A	3.600	B	3.500	B	**7.88**	**0.000***
Research skill	3.684	A	3.700	A	3.600	A	4.333	A	1.21	0.315
Innovation skill	3.684	A	3.900	A	3.700	A	3.917	A	0.19	0.902
Hands-on skill	4.684	A	4.000	B&C	4.400	A&B	3.417	C	**7.74**	**0.000***

* A *p* value lower than *0.05* indicates significant differences of perceptions of students from different subgroups

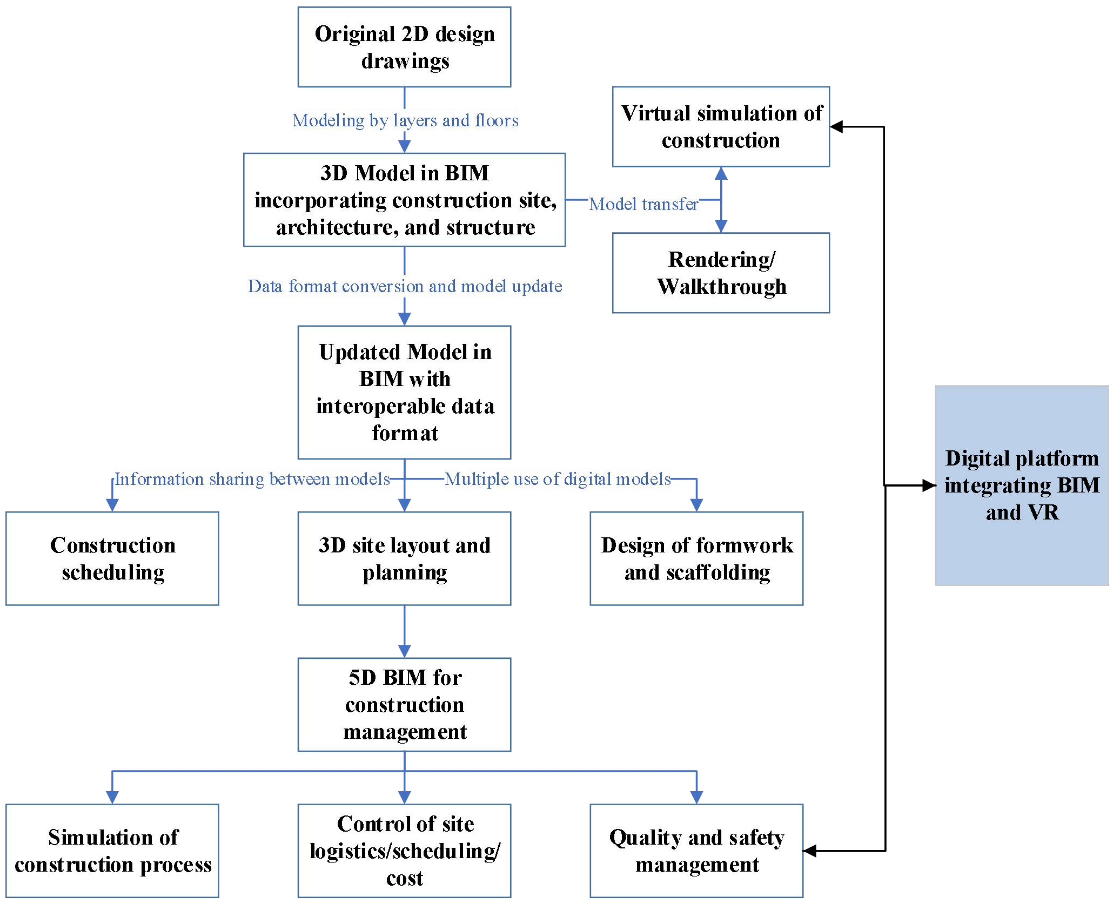
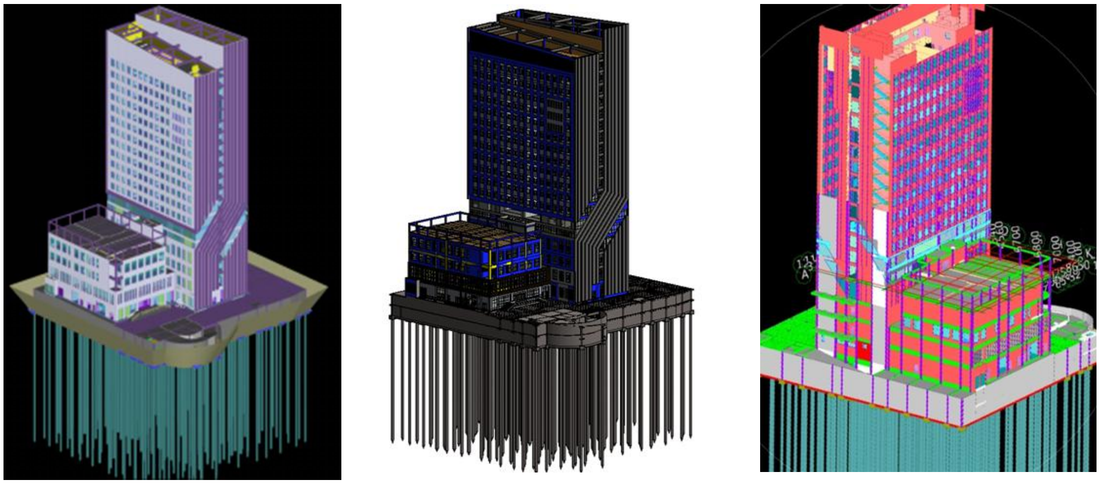


Fig.1. Illustration of the workflow of a typical full BIM application team



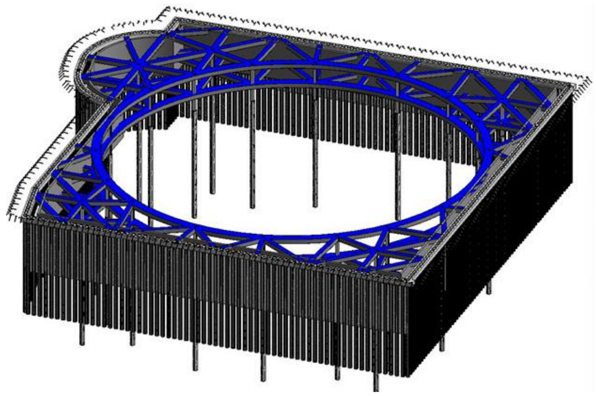
a) Model saved in GTJ file

b)Model saved in Autodesk Revit

c) Model saved in GCL file

Fig.2.Digital models of the studied high-rise building project

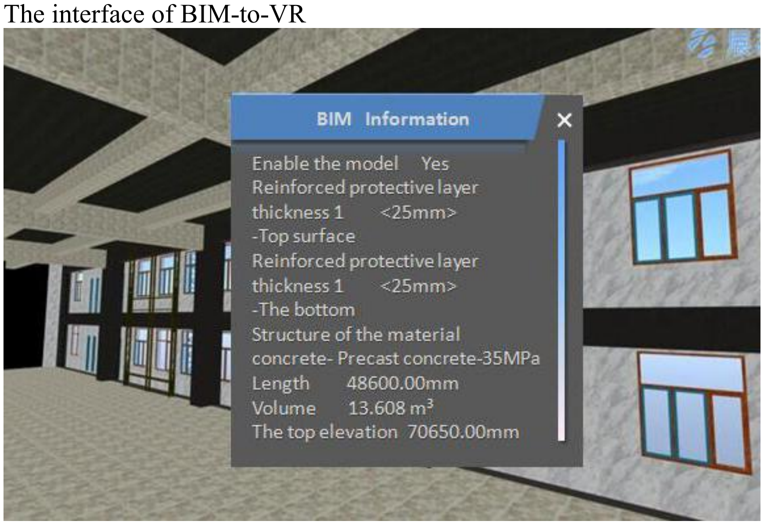
a) Building elevation shown in the digital model



b) Level of detail for foundation pit support

Fig.3. Digital visualization of building family members created in the digital platform

a) The interface of BIM-to-VR

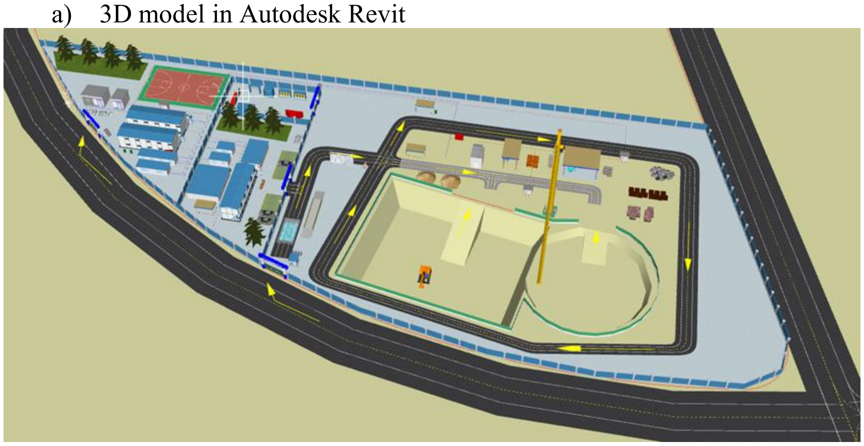


b) Immersing walkthrough in one of the captured scenarios

Note: the text window in the center of Fig.4-b) shows the none-geometric information of the selected building component (i.e., reinforced concrete slab). For example, clicking any building component in the digital model, the corresponding information (e.g., concrete strength) will be displayed in a window similar to what is shown in Fig.4-b).

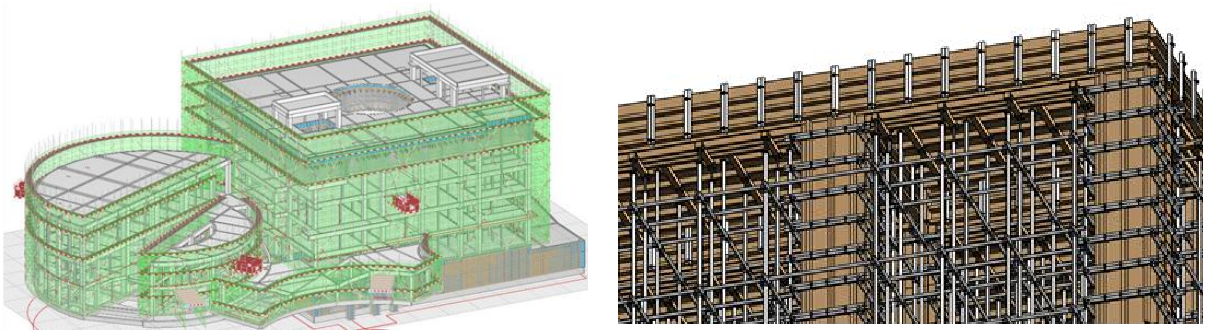
Fig.4. Digital platform linking BIM to VR in the BIM group

a) 3D model in Autodesk Revit



b) 3D site planning at the foundation construction stage

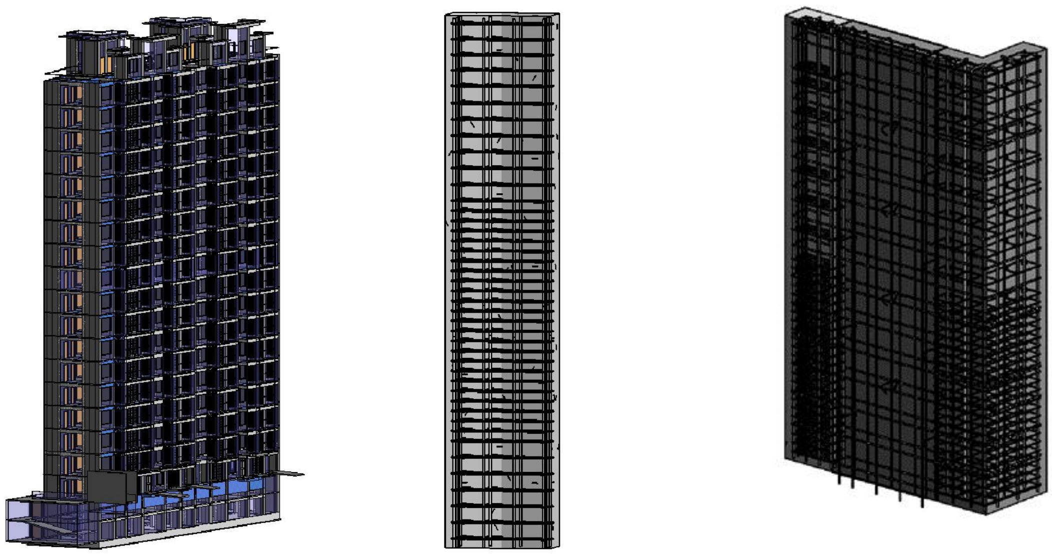
Fig.5. BIM application at different construction stages in the group work of construction planning/scheduling



a) An example of visualized scaffolding in the studied project

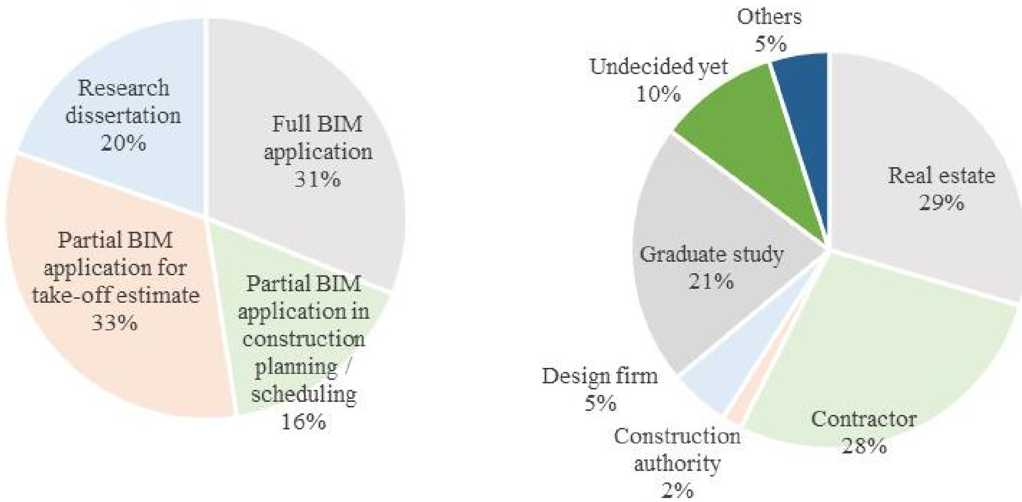
b) An example of wood formwork for reinforced concrete construction

Fig.6. Demonstration of the work in construction planning/scheduling



a) 3D visualization of the studied project b) Column reinforcement c) Reinforcement detals for shear walls

Fig.7. Examples of reinforcement details for a case study project



a) Distribution of students opting different project deliverables

b) Distribution of students choosing different career options
Note: Others included project owner representative, and unspecified options

Fig.8.Background information of student survey sample (N=*61*)